Stanford Synchrotron Radiation Lightsource (SSRL)

Michael Toney
Synchrotron Materials Sciences Division, SSRL
SLAC National Accelerator Laboratory

http://www-ssrl.slac.stanford.edu/toneygroup
1. SSRL & Synchrotron Radiation
   - What is SSRL?
   - What is Synchrotron Radiation?

2. Research Focus
   - How do we use X-rays?
   - Quantum materials (strongly correlated electron systems)
   - Energy materials research

3. Opportunities for grad students
SSRL Overview
SSRL Overview

- **SPEAR3**
  - New ring - 2004
  - 3 GeV, **500 mA**
  - Top-off injection every 5 minutes
  - Reliability >97%; > 5,100 hrs/yr
  - 6 nm-rad emittance

- operates 33 stations
- supports ~1,600 user annually
  - Annual growth >5%
- >400 journal pubs/yr, 1/3 hi-impact
- ~**50 thesis per year**
  - Strong educational focus
- Strong programs in quantum materials, energy materials
SSRL Overview

\[ \gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \]

Frame moving with electron

Laboratory frame of reference

\[ \theta \approx \frac{1}{2\gamma} \]
SLAC: Synchrotron Radiation

Graph showing the increase in log average brightness with the year. The graph compares X-ray tubes and synchrotron sources, with X-Ray Lasers and Moore's Law indicated. The data shows a significant increase in brightness from 1900 to 2000.
X-ray Beamlines / Techniques

- X-ray Scattering/Diffraction
  - Crystallite Properties, Phase, Defects
- X-ray Microscopy (XM)
  - 10s nms morphology & topography
- X-ray Absorption Spectroscopy (XAS)
  - Local Structure & Chemistry
- Photoemission Spectroscopy
  - Electronic structure
X-Rays - Seeing the Invisible

Nanostructures

Positions of Atoms & Molecules

Electron Distributions & Dynamics

Spin Distributions & Dynamics
SSRL Enables & Supports World-class Science in Targeted Areas

Materials by Design

Emergent Behavior

Complex Bio-processes
Substrate phonons enhance superconductivity at the interface

Scientific Achievement
SIMES researchers have discovered a mode coupling between electrons in iron selenide (FeSe) and phonons in strontium titanate (STO) which enhances the superconducting transition temperature in the interfacial layer of FeSe.

Significance and Impact
This coupling points to ways of possibly engineering materials with higher $T_c$ and also gives insight into the general mechanism behind high-$T_c$ superconductivity.

Research Details
– Used molecular beam epitaxy (MBE) to grow single-unit-cell-thick films of FeSe on STO, which were studied in-situ with angle-resolved photoemission spectroscopy (ARPES).

– Observed “shakeoff” bands in the ARPES spectra, indicating electron-phonon coupling of a very specific nature.

– Extracted the electron phonon coupling magnitude and calculated the enhancement of $T_c$, which agrees with other experiments.

BL5: A state-of-the-art ARPES facility

- Excellent control of the photon polarization (7-200 eV)
  - EPU: 2.33 m, 31 pole, LH, LV, CL, CR
- Two complementary branch lines/end stations
  - NIM branch line: high resolution, high stability, low photon energy range
  - PGM branch line: high flux, wider photon energy, small spot, spin-detector
- Sophisticated material synthesis chamber

  \[ \Rightarrow \text{Enable rich science with both depth and diversity} \]

  - High Tc superconductors;
  - Materials with novel spin-orbit physics;
  - Novel low dimensional materials;
  - Surface and interface...

BL5-4
- 7-35 eV
- \( E/\Delta E \approx 20,000 \)
- Normal Incident Monochromator (NIM)
- Exit Slit
- Plane mirror
- 4-jaw aperture
- Undulator

BL5-2
- 20-200 eV
- \( E/\Delta E \approx 40,000 \)
- Scienta hemispherical analyzer
- Sample

\[ > 2 \times 10^{11} \text{ ph/s @ 10,000 RP} \]
\[ 0.2(H) \times 0.1(V) \text{ mm}^2 \text{ (FWHM)} \]

\[ > 3 \times 10^{12} \text{ ph/s @ 10,000 RP} \]
\[ 0.032(H) \times 0.005(V) \text{ mm}^2 \text{ (FWHM)} \]
Sustainable (Renewable) Energy - Materials and Processes – *In-Situ*

- **Photovoltaics (PV)**
  - Si contacts, CIGS, CZTS, OPV, RTP, printing, …

- **energy storage**
  - anodes: Si, Ge, Sn, alloys, Mn hexacyanomanganate, …
  - cathodes: LiMnNiCoO$_x$, LiFePO$_4$, sulfur, Cu hexacyanoferrate, …
Effect of Molecular Orientation on Ultrafast Electron Transfer

Scientific Achievement
Measured dependence of photoexcited electron transfer rate on relative molecular orientation at organic heterojunction interface.

Significance and Impact
Showed that face-on interfaces (larger intermolecular π-electron overlap) have significantly faster electron transfer rates at donor/acceptor interfaces and that control of relative molecular orientation is important to maximize charge generation in organic solar cells.

Research Details
– The core-hole clock implementation of resonant Auger electron spectroscopy was used to measure electron transfer rates on ultrafast sub-50 fs time scales.
– Face-on interfaces show electron transfer (ET) times below 35 fs, whereas edge-on interfaces lead to ET times of > 50 fs.

Work performed at Stanford University and Stanford Synchrotron Radiation Lightsource

Transmission X-ray Microscopy

Capabilities:
- Morphology – 30 nm resolution. 30 µm field of view
- 2D & 3D imaging (density, porosity)
- Elemental/chemical maps
Transmission X-ray Microscopy

Imaging 1895

Imaging now
**Scientific Achievement**

*Operando* imaging shows size dependent cycling characteristics of Ge particles. *In situ* 3D imaging demonstrates fracturing of anode material into completely unconnected pieces.

**Significance and Impact**

This work demonstrates the value in linking electrochemical performance with morphological evolution to better understand battery failure and further the search for high capacity electrode materials.

**Research Details**

- Only Ge particles with diameters larger than a few microns crack during cycling.
- Small particles lose electrical contact by the second cycle.
- The density changes due to lithiation are consistent with partial transformation into a Li$_{15}$Ge$_4$-like phase.

*Upper*: Schematic showing irreversible deformation of the conductive carbon matrix (blue) electronically isolates the small particles, making them inactive in the second cycle.

*Lower*: Volume rendering of Ge particles (a) before cycling, (b) after lithiation, and (c) after delithiation

Time resolved X-ray Science
Multiferroic thin films; Ultrafast thermal transport

M. Kozina et al., *Struct. Dyn.* (2014)
Influence of Amorphous Structure on Crystallization of Different Polymorphs

Outline:
- Deposition
- Crystallization

Deposition

Pulsed Laser Deposition (PLD)

Electrochemical Deposition

Characterization of the amorphous structure:
- Grazing Incidence Pair Distribution Function (GIPDF)
- X-ray Absorption Spectroscopy (XAS)

Structure of crystallized thin films (Identification of polymorphs):
- GIXRD, Powder XRD on scraped films, *in-situ* XRD
- Modeling of structural relationships (LBNL)

Amorphous films

Structure of crystallized thin films (Identification of polymorphs):
- GIXRD, Powder XRD on scraped films, *in-situ* XRD
- Modeling of structural relationships (LBNL)

Crystallization
Summary – Opportunities

• Research opportunities at SSRL
  • PV, energy storage, catalysis
  • Strongly correlated electrons